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Two Howitzer Crew Drill Models

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For this research, Micro SAINT software (Micro Analysis and Design, Inc.) was used to build crew drill models to develop a modeling and simulation approach to weapon system evaluation that could be used to supplement operational evaluation procedures. The intent was to link crew performance directly to system performance. Two models were developed for the Howitzer Improvement Program. Exercising the models over a range of critical task error rates produced results that illustrated how average performance time may degrade very slowly despite errors in selected tasks. It was concluded that crew drill models written in Micro SAINT offer a promising way to assist operational testing and evaluation.

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TWO HOWITZER CREW DRILL MODELS

CONTENTS

LIST OF FIGURES

TWO HOWITZER CREW DRILL MODELS

Overview

Operational sequence diagrams and timelines developed for the Howitzer Improvement Program (HIP) were used to build two crew drill models with Micro SAINT software. The fire-from-road-march drill requires the crew to pull off the road and fire a first round within 60 seconds after receiving a mission order. The 12-round-volley drill requires the crew to sustain fire at three rounds per minute after firing the first round.

The average time and variability for each task were set to ensure crew drill performance within the time required for each drill. Then crew errors were introduced for two preparatory tasks: selecting the projectile and selecting the charge. The chief of section performed a check task on each of these two preparatory tasks before firing occurred. Errors made in either preparatory task required repetition of both the preparatory task and the appropriate check task. Ten task error rates, ranging from zero to 64%, were chosen for investigation. Aggregate crew error rates for the projectile and charge tasks ranged from zero to 87%.

Each crew drill model was run 100 times at each of the different error rates. At individual error rates below 16%, drill time requirements were met in 85 to 100% of drill trials. High error rates had a large impact on variability, but a small impact on average time, a result that was not unexpected since only two tasks (a small proportion of the total number of tasks involved) were subject to error in the models, and extreme values in a statistical distribution typically have a proportionately greater effect on measures of variability than on measures of central tendency.

If real crews can be trained to sustain the task time standards used in these models with error rates at or below 16%, slack time would be sufficient to ensure that occasional errors are absorbed and overall drill time requirements are met. The drill model results illustrate the value of rigorous time standards in training. However, if error rates increase as a function of continuous or sustained operations, then even highly trained crews may be subject to excessive performance variability. The drill model results illustrate how ten-fold increases in variability may occur with little change in task time averages. Slow and small degradation in average performance can accompany large increases in the variability of performance.

Additional crew drill models reflecting other assumptions are planned to build an operational test scenario model for the HIP. A major advantage of Micro SAINT is that models may be run on commonly available personal computers to examine different assumptions and situations.

Approach

Howitzer Improvement Program (HIP) Crew Drill Requirements

Operational sequence diagrams and timelines developed for the Howitzer Improvement Program (HIP) were used to build two crew drill models with Micro SAINT software. HIP gun crews will use automatic fire controls to enable them to respond quickly to fire mission orders (Department of Army, 1988). Gun crews will be trained to perform various crew drills to ensure mission responsiveness. To these ends, the HIP prime contractor prepared operational sequence diagrams (Geer, 1981, Meister, 1985) to examine, study and document the details of performance necessary to accomplish specific missions.

Two of these diagrams are presented in Appendix A. They show networks of interactions among the crew members, the automatic fire control system (AFCS), and external sources of tasking and targeting information for a single HIP vehicle. They diagram functional flows of information and actions over time and events. Just three symbols are used for information (transmit, receive and store) and three for action (operate, inspect and decide). Notes and codes explain each node and flow.

The first diagram is titled MAS Fire Mission. MAS means modified armament system that includes the AFCS. This fire mission diagram begins with mission alert alarm and ends with firing a first round. It shows 110 nodes or points of interaction among crew members and their weapon system.

The second diagram is titled MAS 2nd Round. It begins with recoil from the first round and shows the next round in a volley of fires. It shows 58 nodes or points of interaction for each additional round to be fired.

The HIP prime contractor used the operational sequence diagrams to develop sets of schematics, timelines and assumptions necessary for specific crew drills. The schematics spread crew and system functions over time in seconds. The timelines list key events and their approximate times in approximate cumulative time order. The assumptions describe initial conditions for the weapon system and the crew. The timeline sets for our two drills are presented in Appendix B.

The first timeline set is titled MAS 60 Seconds. It shows a design requirement for the crew to fire a first round from road march in 60 seconds or less. A crew consists of four soldiers: a chief of section (COS), a gunner (GNR), a cannoneer (CAN), and a driver (DRV). The HIP weapon system (SYS) is assumed to be well maintained, supplied and moving along in a state of readiness for a mission order. The crew is assumed to be well selected, trained, rested, and alert for a mission order. The time estimates were derived from expert judgement and experience, and were set to meet the minimum time requirement.

The second timeline set is titled MAS 4 Round/Minute. It shows a delivered-fire design requirement for four rounds to impact a target area in one minute, counting time from the first round impacting a target area to the fourth. The necessary cyclic rate of fire to achieve this is three rounds per minute. Hence, the elapsed time requirement for any one round is 20 seconds counting from firing a previous round. The same crew and system readiness assumptions are made, but the number of rounds was assumed to form a twelve round volley. The time estimates were again set to satisfy the requirement.

These two crew drill requirements were selected for model development because the HIP is moving toward operational testing and evaluation. There is a practical need to estimate task time and error tolerances in crew performance. Such estimates might prove useful in formulating training objectives and in evaluating crew performance. Computer models might even be used to show crews in training why they need to drill toward the kinds of time and error tolerances built into the models. Computer models might help to reduce and evaluate field test data. But, first, there have to be valid models.

This report describes the development of two crew drill models based on work done by the HIP contractor MANPRINT team. Appendix A and B contain products of that work. Our dependence on that work is too great to be acknowledged in a footnote. Our research required direct cooperation and assistance from the HIP Program Manager and the prime contractor. They did exceptionally thorough work which made our work possible. If these models fail to be good ones, the fault is entirely ours. If they prove to be good ones, substantial credit rests with the HIP Project Manager and the HIP prime contractor MANPRINT team.

Technical Objective: Basic Start-Up Models

Although these models are considered to be useful ones, this report cannot properly address the quality or value of the models it presents. Such evaluation depends on what use is made of models as well as judgments about the assumptions built into the models. From our point of view as researchers and developers, questions of validity and verification are premature. These models represent a new start. Our interests and objectives are in the technology for building and understanding crew performance models. However, we are not purists, interested in models for their own sake. We want to build models that can be easily understood and rapidly adjusted for use in the MANPRINT program (Department of Army, 1987). In particular, we believe that crew drill models may help to include the soldier in combat models (Van Nostrand, 1988), and system models designed to supplement the results of operational tests of weapon systems in the early stages of development.

Therefore, these models have been built very simply. They make few assumptions and the assumptions are simple. They have been built using interactive computer software that is easy to learn and use. This system is called Micro SAINT (copyright 1985 Micro Analysis and Design, Boulder, CO). It can be run on commonly available personal computers; the term Micro stands for micro-computer. The acronym SAINT stands for Systems Analysis of Integrated Networks of Tasks.

Micro SAINT software (Laughery, 1985) enables one to build integrated systems of networks (i.e., networks of networks), but the models we discuss here are basic stand alone networks. The software provides several random event distributions (normal, gamma, exponential, and rectangular) from which one can draw samples. We used rectangular distributions because they are the simplest. Although Micro SAINT supports complex contingency tables and dynamic modeling, it was elected to use error-correction loops, in essence simulating the principle, "If it is wrong, do it again until it is right". No changes were made in the time limits for repetitions. This kind of simulation of a system is very mechanical, but one can introduce complexity to the simulation later. For now, it is desired to keep the start-up models simple so they can be easily understood (Chubb, Laughery & Pritsker, 1987). It was desired to understand each drill network before linking the drills in scenario networks.

Errors may occur anywhere in a human network, of course, and no crew position is completely free of error. However, in these initial models, errors are limited to two critical tasks. Only the simulated GNR and CAN make errors, and the simulated errors are made in two preparatory tasks that are checked by the COS; namely, the retrieval of projectiles by the CAN and the retrieval of charges by the GNR. The simulated checking process is assumed to be flawless. When the COS finds an error in either retrieval task, that task is repeated. The model design for simulating crew error provides an opportunity to see how crew error rates might impact on crew drill completion times.

Ten error rates were examined, varying from 0% to 64%. For simplicity, we gave the two individual preparatory tasks the same error rate for each set of 100 trials. The individual rates are important for training and measuring the performance of individual soldiers, but collective training and crew performance generates rates that depend on combinations of individual tasks. We sought in the start-up models to keep the relationship between individual performance and crew performance as straightforward as possible. The aggregate crew error rate (P_{AE}) for two independent tasks (P_{E1}, P_{E2}) is equal to the sum of the individual probabilities minus their product, i.e., $P_{AE} = (P_{E1} + P_{E2}) - (P_{E1} \times P_{E2})$. Thus, individual task error rates of 64% yield an aggregate crew error rate of 87%. (The aggregate crew error rates for individual task error rates of 1%, 2%, 4%, 8%, 16%, 24%, 32%, and 48% are, respectively, 2%, 4%, 8%, 15%, 29%, 42%, 54%, and 73%.)

Although simple in computation, 87% may seem to be an unreasonably high rate of error. However, a positive feature of modeling, is that we can examine variables beyond reasonable limits and do so with other variables under perfect simulated control. For example, in these two drill models, the "perfect" chief of section always catches every error and makes sure there are no errors before firing. There are no simulated short or long rounds because of crew error. Only the time to completion is free to vary in computer trials of these two drills, and the only "cause" of exceeding drill time standards is crew error in two critical tasks. Without error, the drill models meet required time standards because they were built to do so.

With low error rates, the models deliver exactly the kind of results desired. The interesting questions and observations to be made from running such models are those suggesting how, how often and how badly system performance may degrade when crew performance degrades.

For the rest of this report, descriptive terms have been substituted for HIP-specific acronyms. The MAS 60 Second requirement is described as the fire-from-road-march drill or march fire. March fire requires the crew to pull off the road and fire a first round within 60 seconds after receiving a mission order. The MAS 4 requirement is described as the 12-round-volley drill or volley fire. Volley fire requires the crew to sustain firing at three rounds per minute for twelve rounds after firing the first round. This change in terminology separates the drill models from HIP contract history and emphasizes ARI technical interest in developing basic start-up models as the first step toward simulated crew operations technology for MANPRINT.

Results

Fire-from-Road-March Drill Model

March fire timelines are shown in Figure 1. This figure shows each task in the model network in sequence from "SYS Alarm!" to "SYS Fire!" (An understanding of the exact order in which specific tasks must be performed can be obtained from the schematic on page B-2.) The average start time is time spent waiting on a preceding task. Note that "COS Direct driver" begins immediately after "COS Press confirm" which is a fixed time task. Note further that "COS Press arrive key" begins at the mid-point of "COS Direct driver" between the minimum and maximum times. That mid-point is the average of a rectangular distribution of equally probable performance times. The model takes 16 seconds, on the average (with a minimum of 12 seconds and maximum of 20 seconds), to simulate finding a place to stop and stopping. That eight second spread is filled randomly on every computer trial or run of the model. Exact times built into the model are presented in Appendix C.

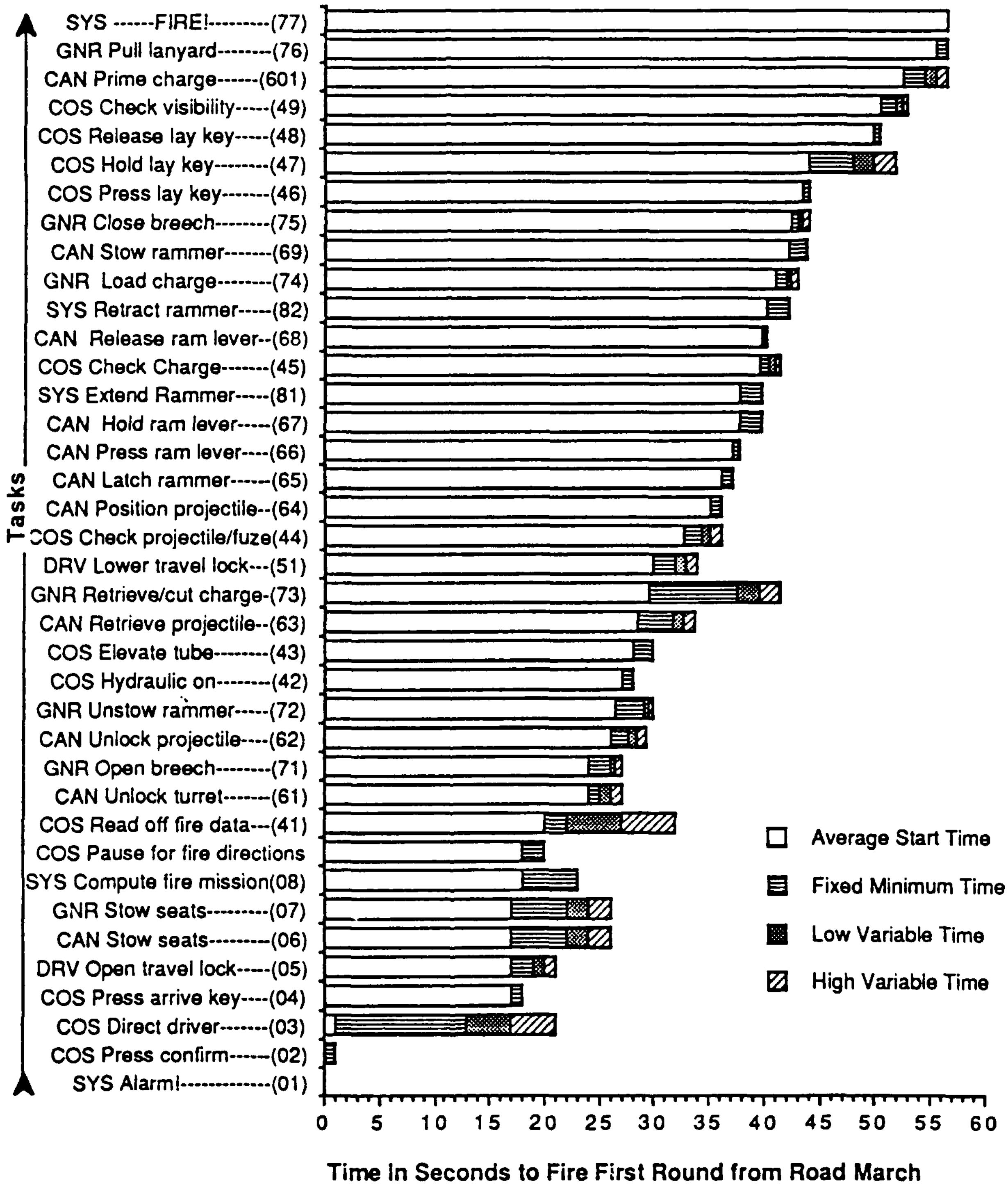
Since the sequence shown is based on average performance times for each task, the mid-point of variable time is regularly the starting moment for some later tasks. Task numbers shown in parentheses were used to index the model. They may be used conveniently here to point to such instances. For example, tasks 4 through 7 start immediately after task 3. Other contingencies may be inferred from end-to-start alignments, but they may be separated by intervening tasks on the chart. For example, task 8 follows upon task 4.

The critical path through this particular network sequence happens to flow through the COS, GNR and SYS tasks including CAN only at priming the charge (601). DRV is on the path only in being directed by COS to an emplacement. The critical path is not shown on the chart because it changes depending on task times and error conditions. This particular sequence is based on fixed conditions of average time for each task and no errors. When errors and corrective actions are introduced by the model, the critical path changes back and forth between GNR and CAN tasks.

Errors at "CAN Retrieve projectile" (63), and "GNR Retrieve/cut charge" (73), were simulated with detection algorithms at "COS Check projectile/fuze" (44) and "COS Check charge" (45). "If-then" loops at each check task generated repetitions of associated retrieval-check task sequences if an error occurred.

Ten individual task error rates were explored. They were 0%, 1%, 2%, 4%, 8%, 16%, 24%, 32%, 48% and 64%. This effort stopped at 64% because the aggregate crew error rate from either one or both of the round preparation tasks approaches 90%. When chance produces at least one time-consuming error in nine out of ten drills and no errors are allowed to get by, it can take a long time to complete a drill. When large numbers of error-laden drills are simulated on a personal computer, run times can increase from a few minutes to hours. As a practical matter, 64% seemed high enough as an upper limit since the aggregate crew error rate is equivalent to 87%.

Figure 1
March Fire Timelines



The exploration was begun with a doubling rate scale which can be seen up to 16%, but it was quickly found that low rates made little differences in means but larger differences in variability. We then introduced half steps at 24% and 48% to look more closely at this robustness in means relative to variability.

The statistics for all ten error rates based on 100 computer drill trials per rate are presented in Appendix D. A graph of the results for five of the error rates is shown in Figure 2.

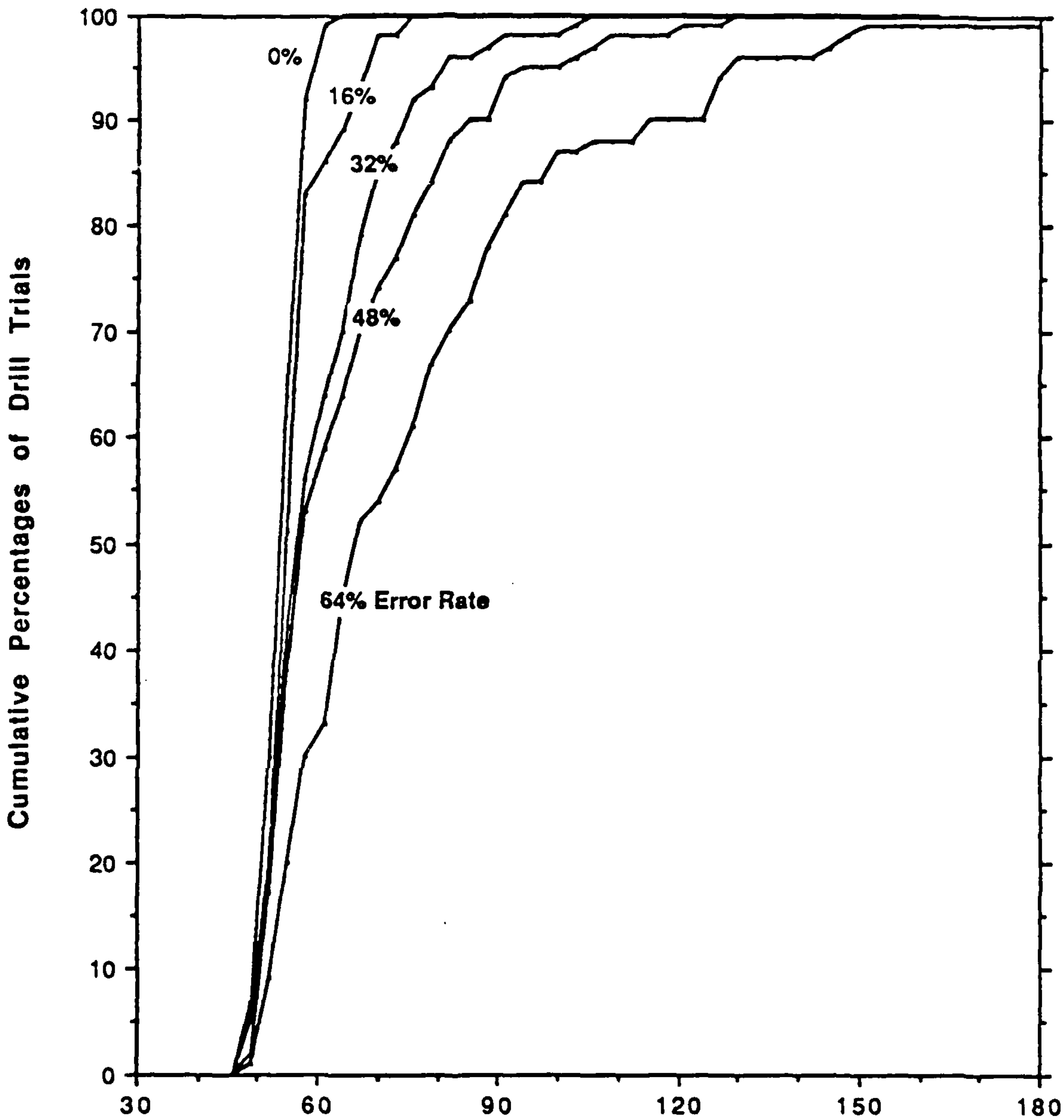
The 0% curve shows that all error-free drills took less than 60 seconds. Minimum time was 46 seconds for 0% and every other error rate. The common point of origin for these curves is not a fact of nature nor is it a computational necessity. It results from our use of a network model and the number of runs or trials per error rate. It is the critical path time for the lowest built-in task times, which is a network model feature. It happened because 100 trials was enough to insure that the least-time path occurred at least once for each error rate. It is a reminder that we are looking at a simulation of crews trained to a set of narrow time standards and, by model design, effectively maintaining those standards.

A counter-intuitive feature of this picture is the tight clustering of the stems for 0% through 48% error rates up to the 50th percentile of the cumulative distribution. The 50th percentile is the median. Median completion times for error rates at or below 48% are well within the 60 second requirement. The aggregate crew error rate equivalent to a 48% individual task error rate is 73%, or seven in ten drills with at least one crew error. Even the highest error rate yields a median time less than 70 seconds. These medians illustrate the robustness of average times in this model.

Increasing variability can be seen in the progressive growth in the right-hand tails of the distributions. Yet that growth is constrained for individual task error rates at or below 16%. All of the small error rate curves are contained within that thin region shown between 0% and 16%. To see constrained variability, read across the 85th percentile to intersect the 16% curve and then to the time scale. Even the 85th percentile appears to be robust in the face of considerable error. Among crews as good as the simulated crews, the 60 second requirement might be met in spite of critical task error rates up to one error in six drills or aggregate crew error rates up to three errors in ten drills.

At high task error rates, however, the frequencies of long completion times increase rapidly. More than one-third of drill trials fail to meet the 60 second requirement at 32% and 48% task error rates. More than two-thirds fail to meet it at the 64% error rate. These results illustrate potential zones of intolerable failure.

Figure 2
Fire-from-Road-March Drill Times by Error Rate



Time in Seconds to Complete Drill in 100 Computer Trials per Error Rate

12-Round-Volley Drill Model

Volley Fire timelines are presented in Figure 3. This drill model begins where the march fire drill ends, but it is not meant to be run or practiced in tandem with the march fire drill. This drill assumes that the weapon has been prepared for volley fire. Projectiles have been fuzed and charges have been cut in readiness for a volley, fire-for-effect. Time standards differ from march fire. The two critical tasks take less time. The chief of section checks projectiles and charges; the AFCS has already been set. The figure shows just one round after the first in a series of thirteen. Interpretation follows that for Figure 1. The difference is that the required 12-round time is not shown; it is 240 seconds for 3 rounds per minute.

Figure 4 presents results for volley fire in a series of error rate curves. The curves are separated more than they were for march fire. The separation results from repetition and the accumulation of time losses from round to round. The interpretation, however, is much the same as it was for march fire.

In particular, the drill time requirement was met 85 to 100% of the time with individual task error rates as high as 16%. But note that the curves do not originate at a common point. Repetitive models show their built-in differences. No simulated crew operating at a 64% task error rate meets the required time. Yet lower error rates make the drill time requirement some of the time.

In this model, median time is below the required minimum time at task error rates as high as 24%. While that is lower than the highest tolerable rate in march fire, it still demonstrates dependable performance in spite of considerable error. Sustained fire is more sensitive to error, however, and the potential for failure to meet time criteria is greater than for march fire.

Figure 3
Volley Fire Timelines

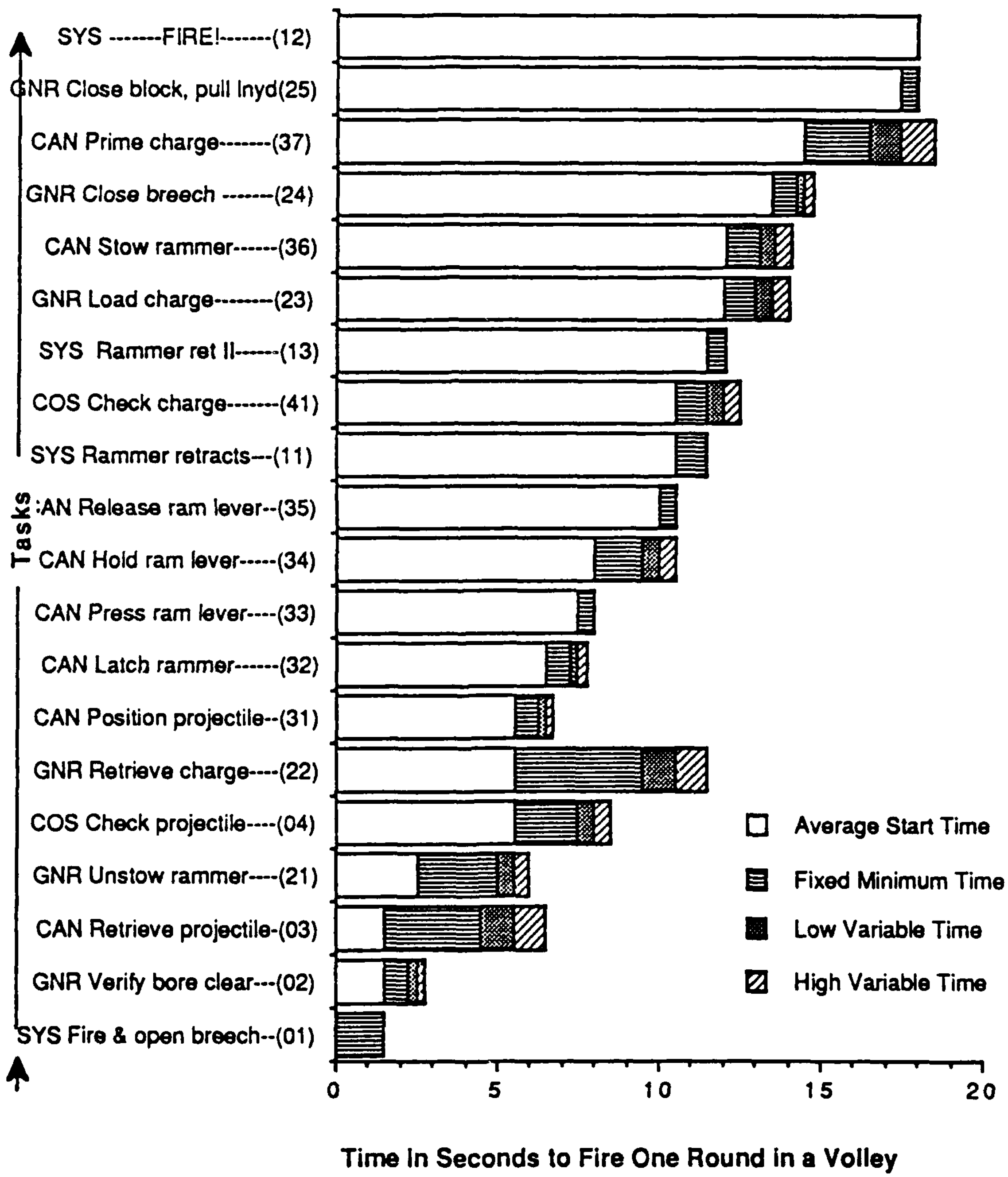
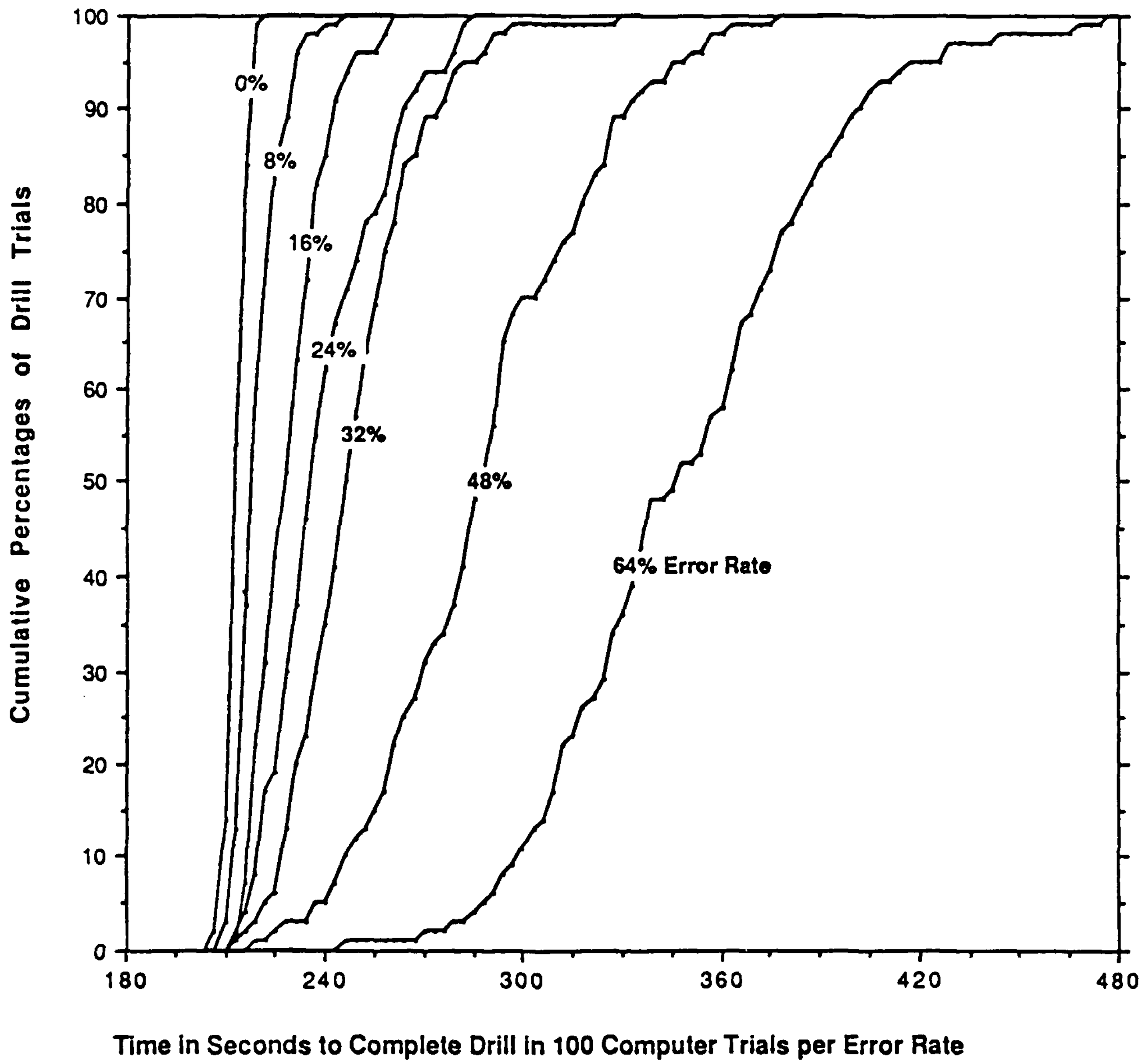


Figure 4
12 Round Volley Drill Times by Error Rate



Implications

To summarize and directly compare overall results for our two models, ratios were computed to see the increases for each error rate relative to zero error. Such ratios were computed for average times and for the standard deviations. The relative increases for both statistics derived from the two crew drill models are shown in Figure 5. For the curves representing averages for volley fire (VF) and march fire (MF), each point on the graph represents a ratio determined by dividing the average time of mission completion at the specified aggregate crew error rate (i.e., 2%, 4%, 8%, 15%, 29%, 42%, 54%, 73%, or 87%) by the average time of mission completion at the 0% error rate. Similarly, for the curves representing variability for VF and MF, each point on the graph represents a ratio determined by dividing the standard deviation of mission completion time at the specified aggregate crew error rate by the standard deviation of mission completion time at the 0% error rate.

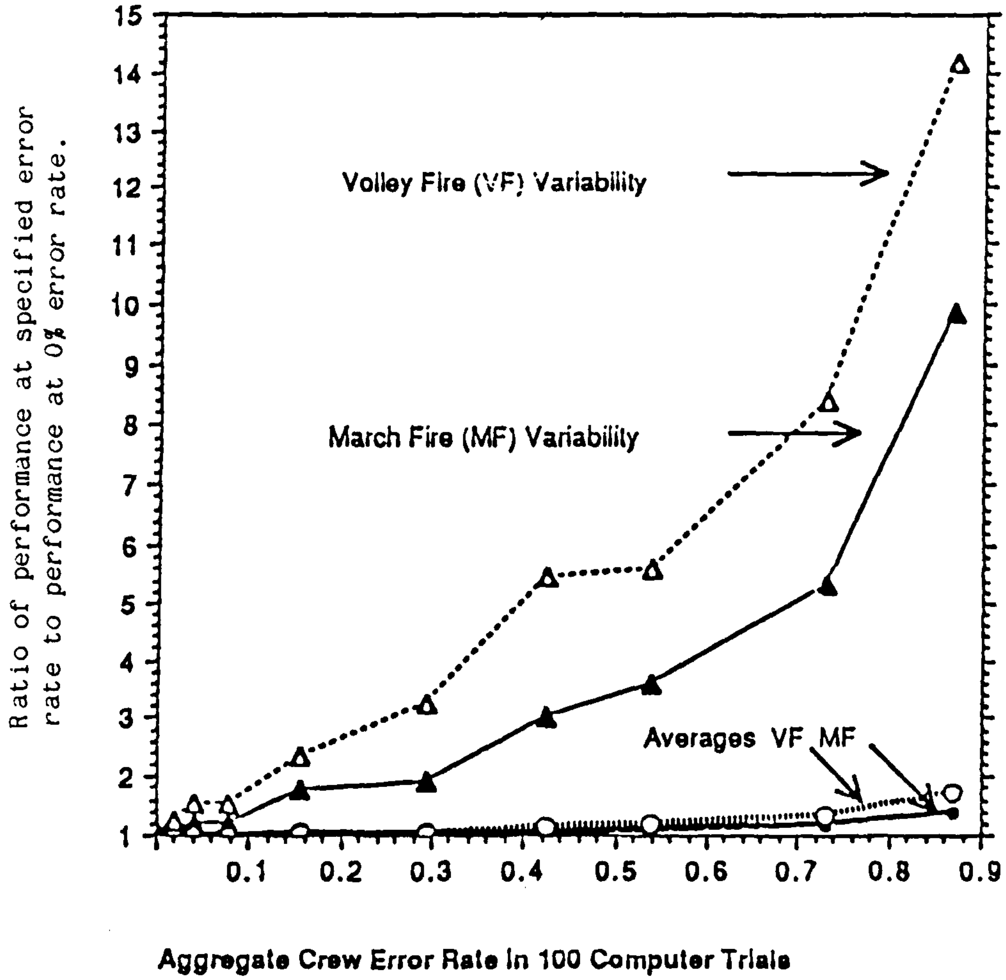
The robustness of average time over error conditions is clearly shown for the two crew drill models. Even with high error rates, the relative increases are less than two-fold. The standard deviations, however, increase ten-fold and fourteen-fold. The relatively small changes in averages can be explained in two ways: (1) error was built into only two of the many tasks being simulated, and (2) one of those two tasks, (retrieving the projectile) overlapped in time with the other task (retrieving and cutting the charge) in such a way that the time involved in repeating the former partially overlapped with the time involved in initially performing the latter (e.g., see page B-2), thus causing the average to increase more slowly with increasing error rate than if the two tasks did not overlap. The larger increase in the standard deviations compared to the means was not unexpected because it can be demonstrated that extreme values in a statistical distribution have a proportionately greater effect on measures of variability than on measures of central tendency, and thus task times produced by high error rates will produce proportionately greater changes in standard deviations than in means.

Nevertheless, the increases in variability against the apparent robusstness of the averages seem to be important observations. Another expression of the same phenomenon from these computer runs is seen in the apparent ability of "well trained, well rested, well equipped" simulated crews to meet drill time standards 85% of the time with critical task error rates as high as 16%.

These start-up model observations may have some useful "if-then" implications which are oriented toward crew training and modeling sustained or continuous operations. If real crews can be trained to sustain the kinds of task time standards used in these models, they may learn to satisfy demanding drill time requirements. Whatever else, the drill models and their results illustrate the value of rigorous time standards in training.

Another potential training application is in the control of errors. Specifically, the models might be used to show crews how important it is to create slack time to absorb occasional errors. Model-based drill training might be used to encourage a new performance method called "error management" (Frese and von Rosenstiel, 1988). This approach aims to reduce or eliminate

Figure 5
Impact of Error
On Average Time and Variability



the negative consequences of errors rather than pretending that errors never happen.

If error rates increase as a function of continuous or sustained operations, then even highly trained crews may be subject to excessive performance variability. The drill models results illustrate how intolerable increases in task time variability may occur with literally no change in task time averages. Slow and small degradations in average performance can be accompanied by large increases in the variability of performance.

There is something paradoxical about consistently high standards and slowly changing averages being associated with rapid increases in intolerable failures. Our start-up models show it can happen, but the real world process is not simple. We suspect that some kind of progressive concatenation of errors may be involved when there are several interacting team members and their individual performances gradually decay under continued performance stress. Although we have not modeled "stress" or fatigue decay, we have modeled the presumed consequences, error and increasing error. It is possible to consider the changes generated by increasing error rates as expected performances in continued or sustained operations. This line of thinking suggests that modeling to understand the concatenation or cascading of error in crew drills might provide leverage against performance decay under stress.

Note that in Figure 5, the aggregate crew error rate has been used rather than the individual task error rate on the x-axis. We made this change to focus attention on the simulated crews in considering these relative increases. The increases in variability shown here results from right-hand tail growth. That lopsided growth is based on accumulated losses in time generated by a simulation that will not fire a badly prepared round. Less dramatically, quality control is rigid and time, rather than quality, is lost.

The Boolean algebra and Venn diagrams associated with the computation of aggregate crew error rates from the individual task error rates lead us to deal with three elements. The computation is as simple as a Venn diagram. The aggregate crew rate is the sum of the individual task rates minus the product of the two rates. This computational procedure is valid for two tasks having a single error rate or different error rates.

However, the procedure does not weight the elements according to their time penalties as these occur in our models. Note that we are not saying a probability estimate should do so. Instead, we observe that the three error elements represent different penalties which contribute differently to the tail growth in time for mission completion observed in Figure 5.

Each individual task being repeated has its expected time penalty. When both tasks must be repeated, the time penalty may be as much as the sum of penalties or it may be no greater than the largest penalty, depending on the sequence and parallelism in the task network. It is believed that the two critical tasks in these two models were in sequence with little overlap in time in most runs. If so, then high error rates with high likelihoods of joint errors would generate large summed penalties. In effect, the tail grows much faster when both critical tasks must be repeated.

The growth may further increase if the chief of section becomes a bottle neck and corrections must wait for inspection. In any case, it appears that growth in variability accelerates more rapidly than the average time partly because of compounded time penalties. To find out if this is so, there is a need to set up the software to count error compounding and delays within crew drill trials. These "simple" models are not as simple as they appear.

The next steps in development toward a simulated crew operations technology (SCOT) are technical ones. The modeler needs to satisfy himself that he understands how these models work. Crew drills may be decomposed or simplified still further. Assumptions and choices of sampling distributions need to be explored. While such technical work is being done, the timelines and geography for an operational test scenario may be developed by operational testers and eventually incorporated into the models.

A major advantage of modeling in Micro SAINT is that interested parties may readily check results and test different assumptions. Micro SAINT software models may be run on commonly available personal computers. The practical result is that complex networks of networks can be assembled from component parts. A distributed development effort can be organized using the common language of Micro SAINT. Some information on acquiring and using Micro SAINT models is presented in Appendix E.

Conclusions and Recommendations

Two crew drill models have demonstrated potential for estimating the consequences of critical task errors. Model results have shown how average performance time may degrade very slowly in spite of errors if crews can meet rigorous task time standards. Whether or not real crews can do so is an empirical question beyond inference from models, but the models do illustrate the value of training to such task standards. They also suggest that operational performance requirements may be satisfied by training to such task standards. Therefore, it is concluded that crew drill models written in Micro SAINT offer a promising way to study time and error measures before training and testing real crews.

Crew drill models may also provide ways to evaluate soldier performance in operational testing under simulated field conditions. In particular, error rates may be systematically introduced to simulate likely consequences of stress and fatigue in continuous or sustained military operations. The present models were limited by design to simple procedural tasks and just two critical tasks. The simulated chief of section never made an error of judgement in checking rounds or charges. There were no other errors of judgement or process. There was no context of events, no scenario of move, shoot, communicate, resupply, maintain and do it all over again, hour-by-hour, day-after-day. There were no breakdowns or interruptions, and no sudden changes as is characteristic of battlefields. Such events may be built into an operational test scenario simulation. If a variety of crew drill models were run in such a simulated environment, we would have the beginnings of simulated crew operations technology (SCOT). We recommend that SCOT be developed to include a number of simple crew drills that are combined with command and control actions during operational test scenarios. ARI intends to conduct further research toward this end.

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Appendix A

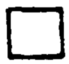
Operational Sequence Diagrams

Note: All of these materials are working documents provided by the HIP prime contractor MANPRINT team. They are not official or final estimates of crew or system performance.

OPERATIONAL SEQUENCE DIAGRAM SYMBOLOGY
(Geer 1981)

Symbology

 Operate - an action function, to accomplish or continue a process. (Sometimes used for received information)

 Inspect - to monitor or verify quantity or quality. An inspection occurs when an object is examined. (Sometimes used for action)

 Transmit* - to pass information without changing its form.

 Receipt* - to receive information in the transmitted form. (Sometimes used for stored information)

 Decision - to evlauate and select a course of action or inaction base on receipt of information.

 Storage - to retain. (Sometimes used for transmitted information)

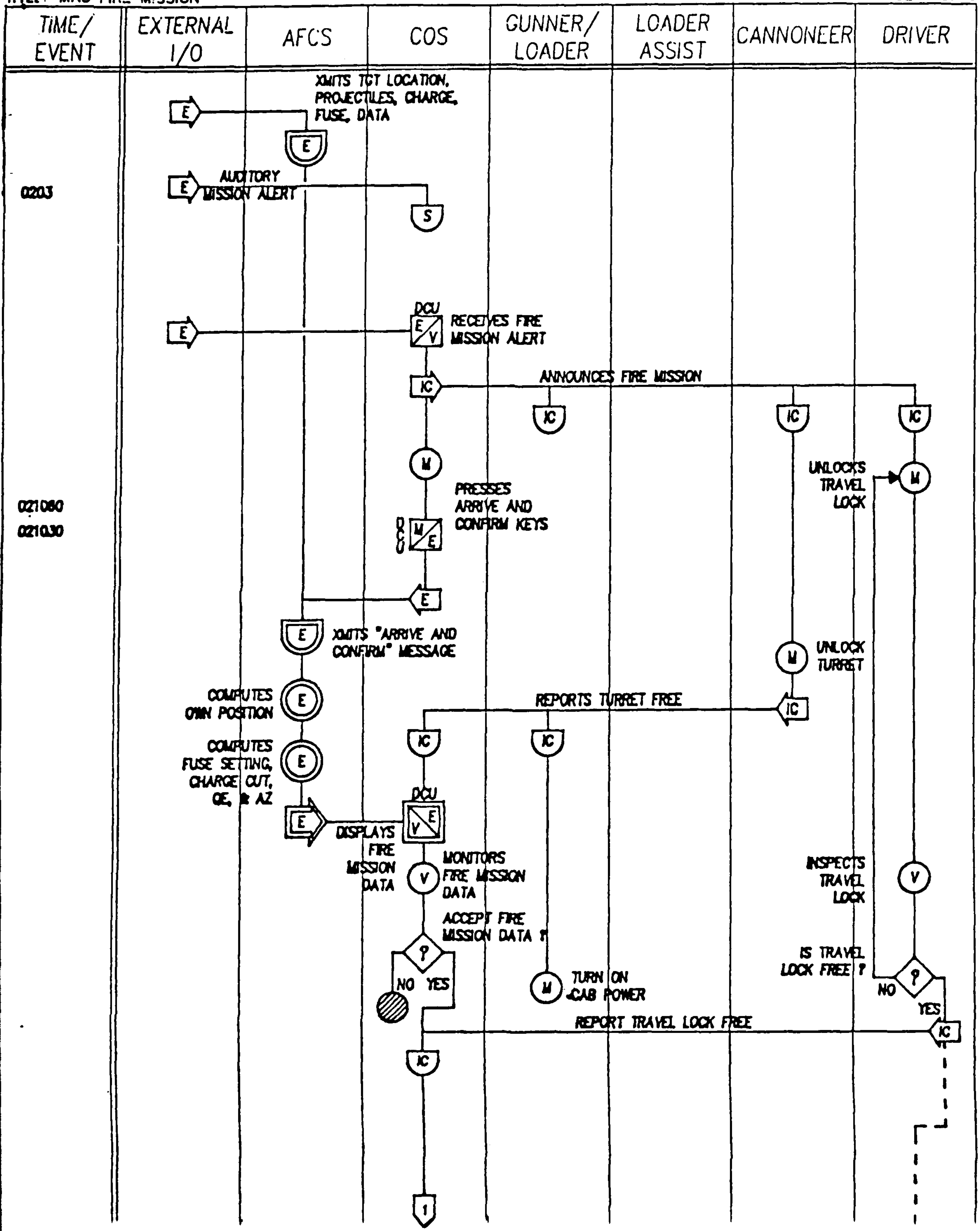
* - Mode of transmission and receipt is indicated by a code letter within the

 and  symbols.

V - Visual
E - Electrical/Electronic
S - Sound (verbal)
IC - Internal Communication
EX - External Communication
T - Touch
M - Manual
W - Walking
H - Hand Deliver

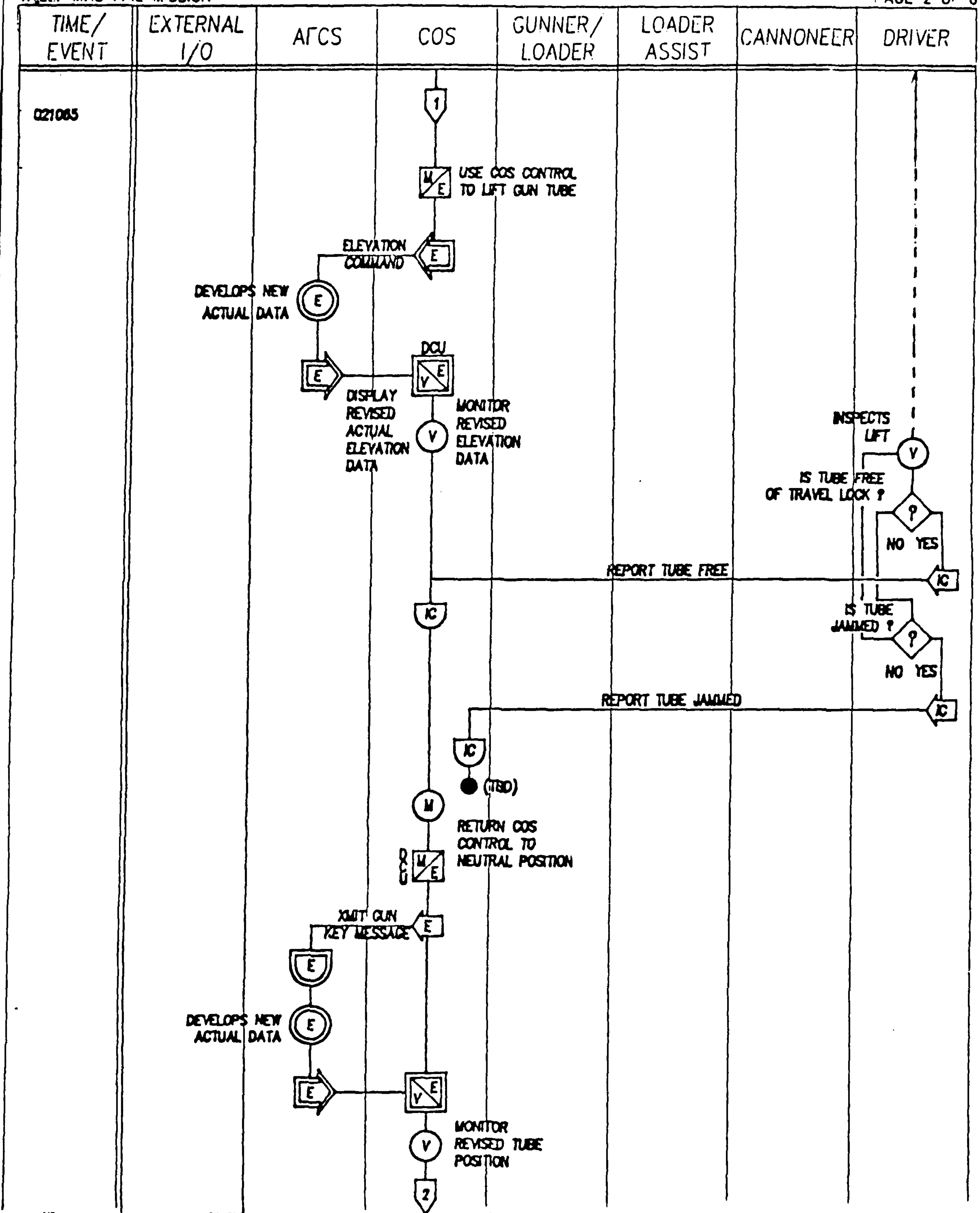
HIP OPERATIONAL SEQUENCE DIAGRAM

TITLE: MAS FIRE MISSION



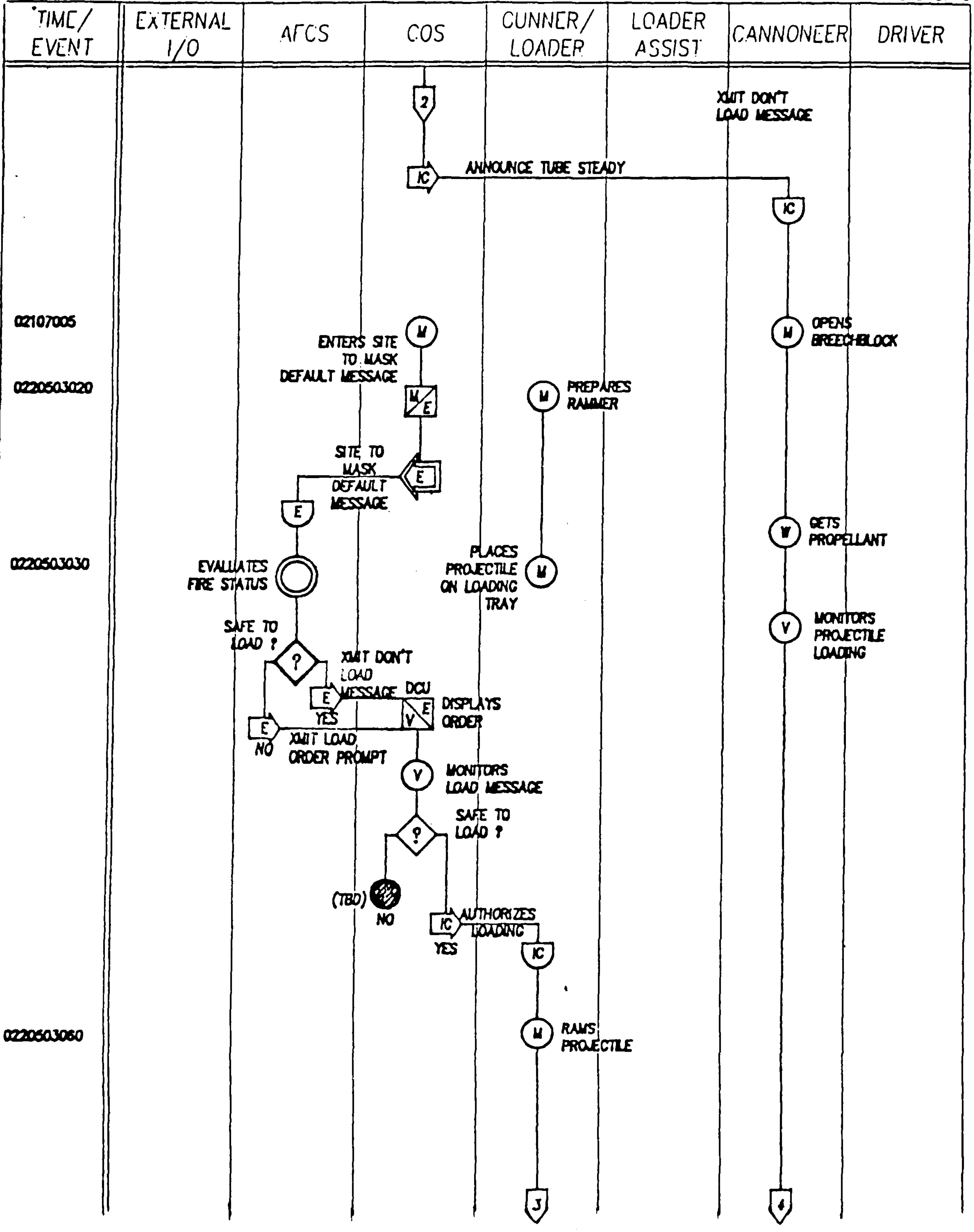
HIP OPERATIONAL SEQUENCE DIAGRAM

TITLE: MAS FIRE MISSION



HIP OPERATIONAL SEQUENCE DIAGRAM

TITLE: MAS FIRE MISSION



HIP OPERATIONAL SEQUENCE DIAGRAM

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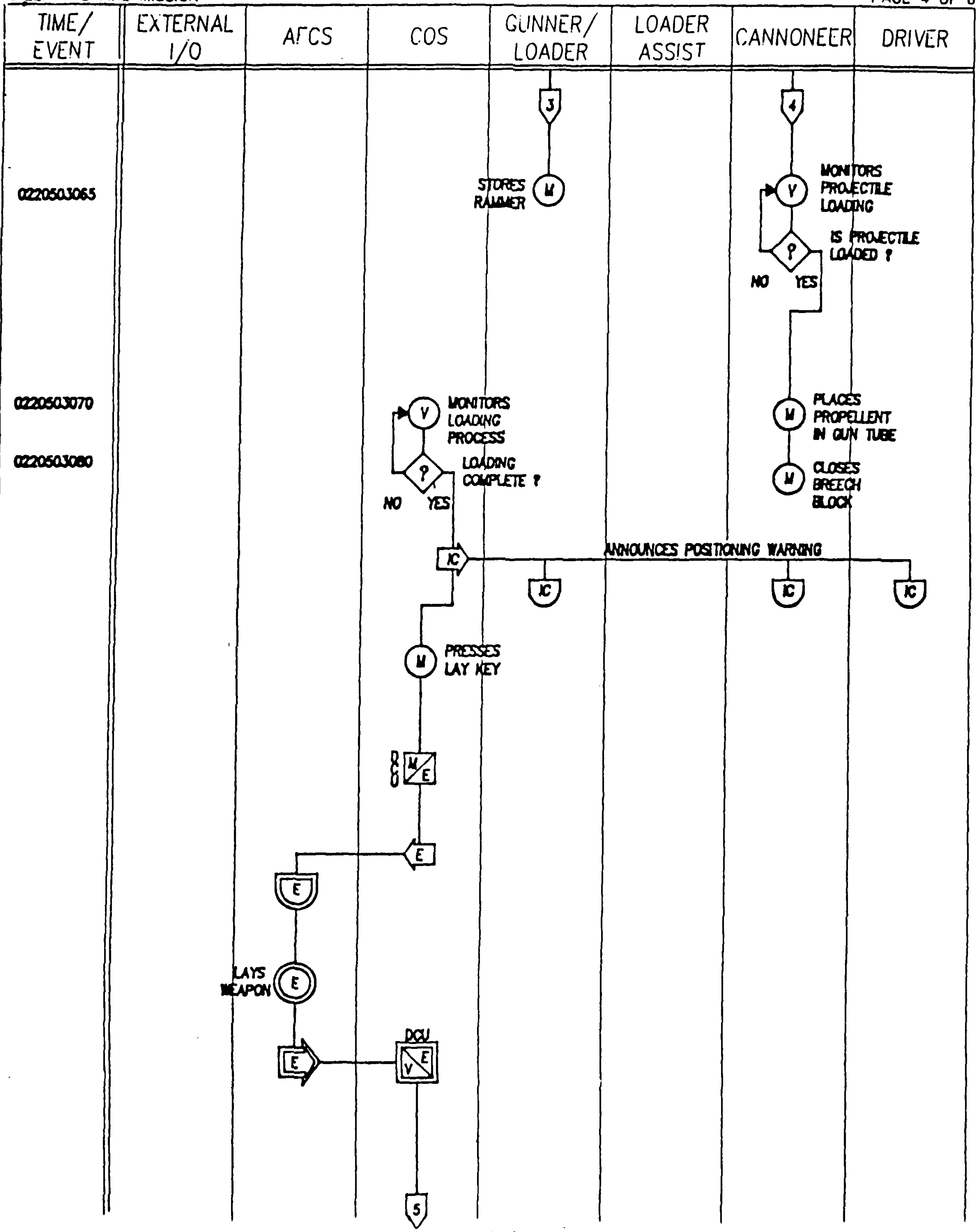
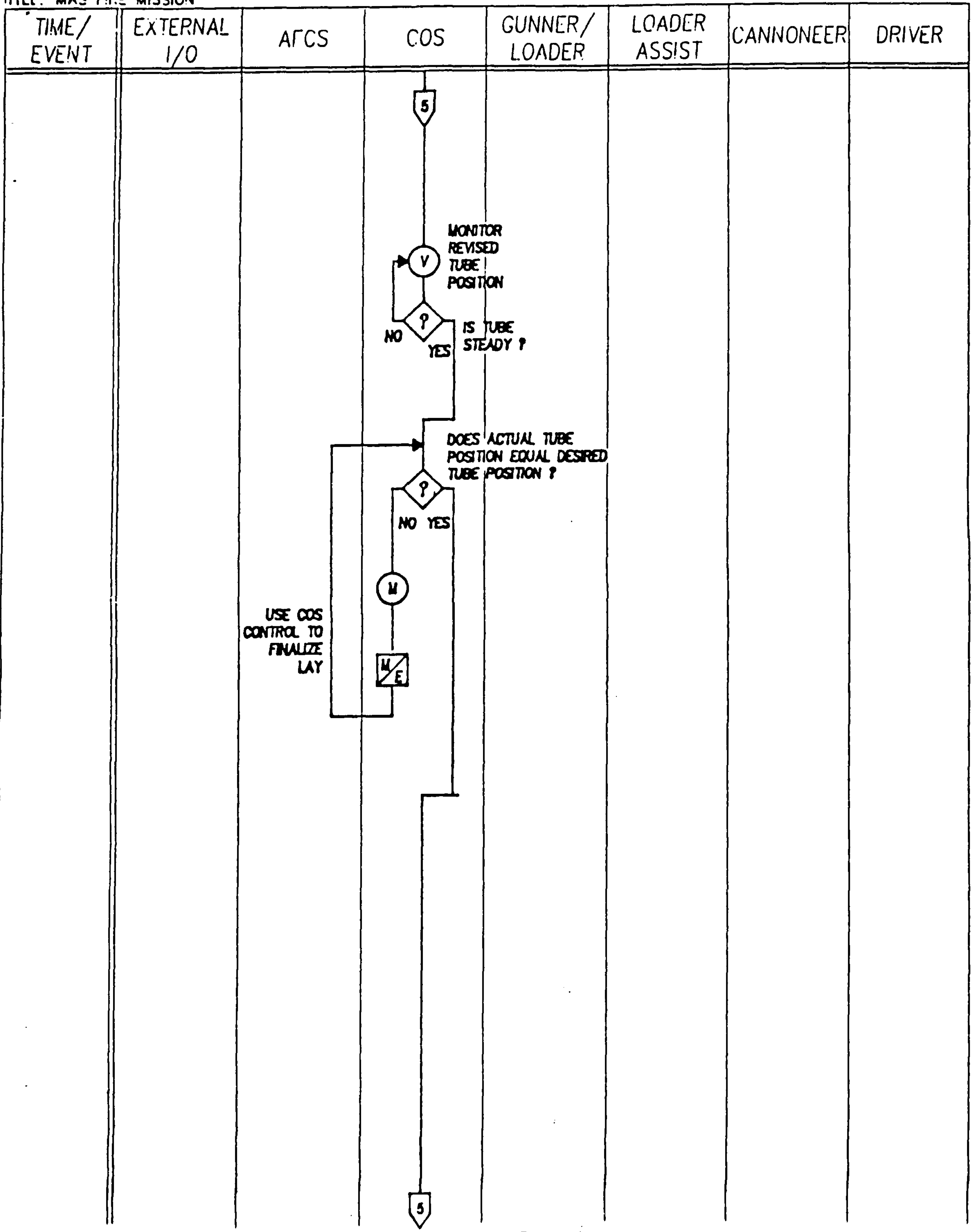


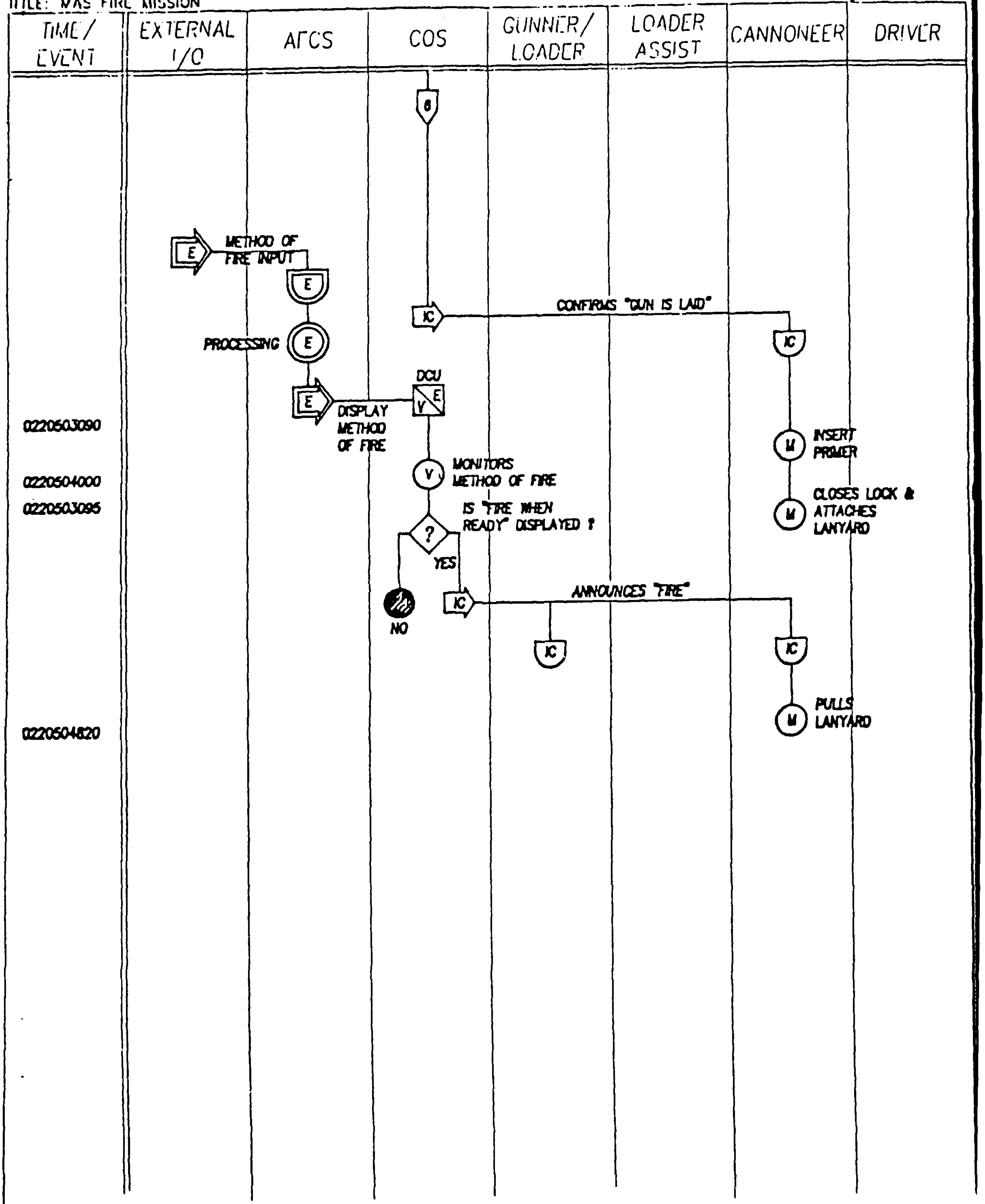
HIP OPERATIONAL SEQUENCE DIAGRAM

TITLE: MAS FIRE MISSION



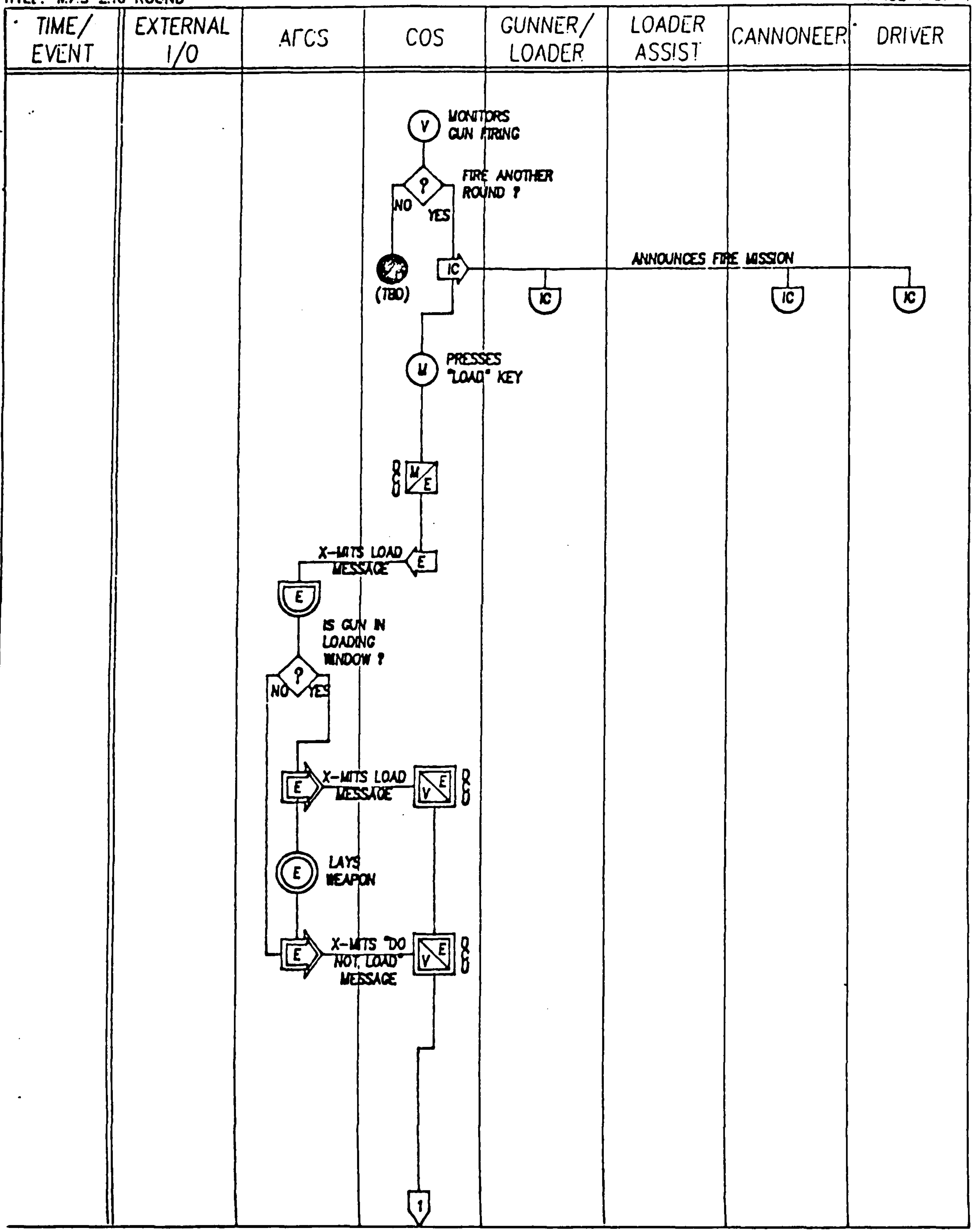
HIP OPERATIONAL SEQUENCE DIAGRAM

TITLE: MAS FIRE MISSION



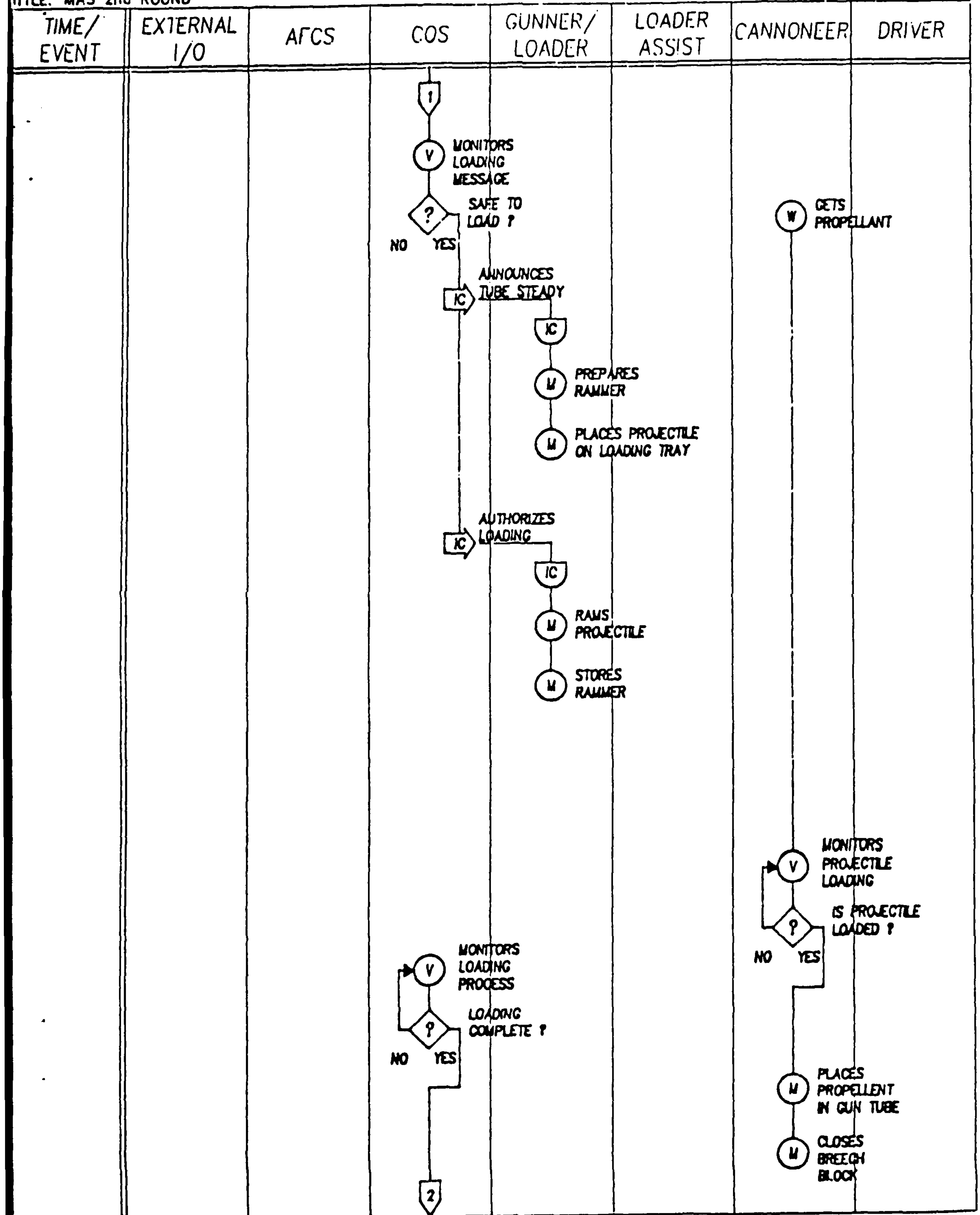
HIP OPERATIONAL SEQUENCE DIAGRAM

TITLE: MAS 2nd ROUND



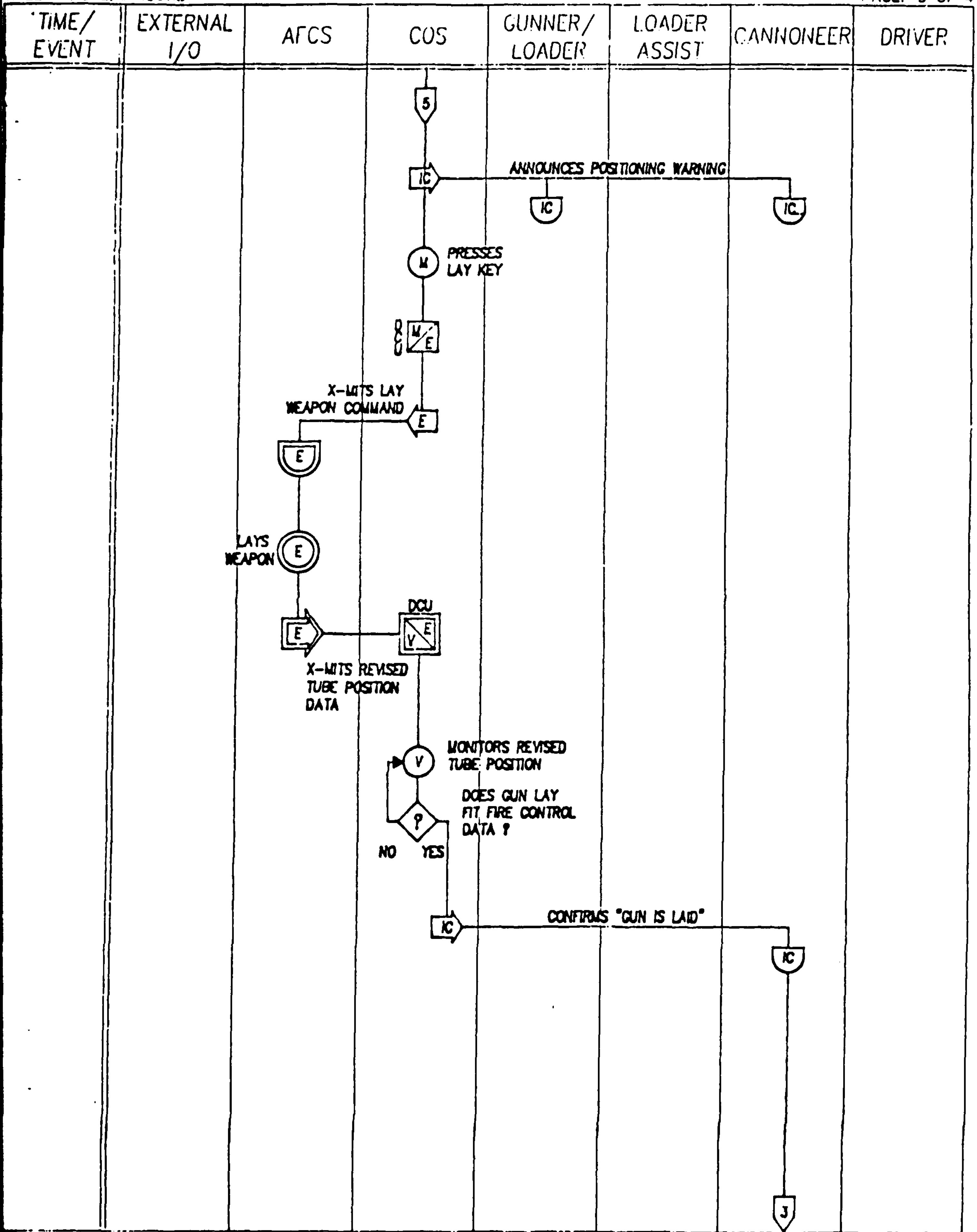
HIP OPERATIONAL SEQUENCE DIAGRAM

TITLE: MAS 2nd ROUND



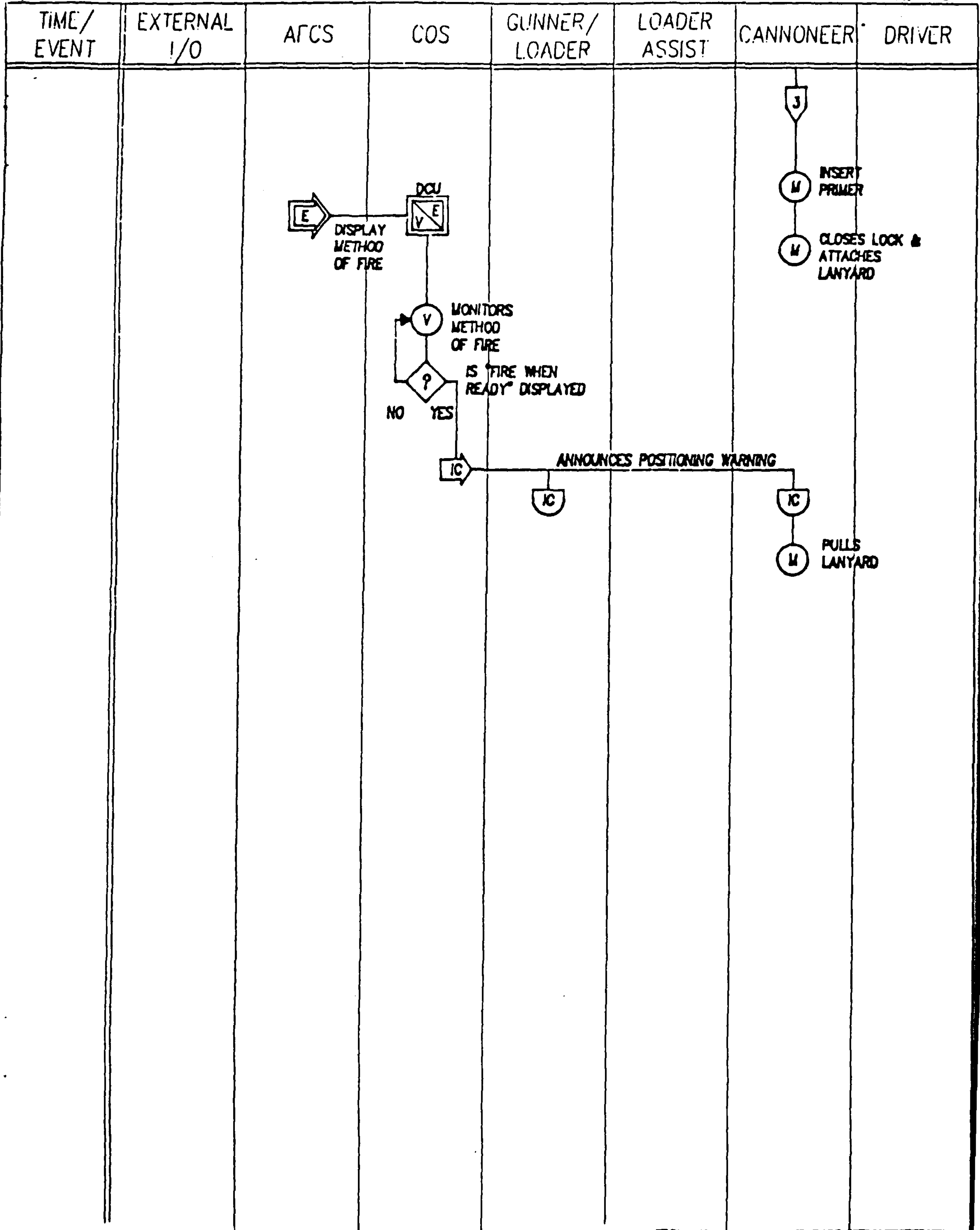
HIP OPERATIONAL SEQUENCE DIAGRAM

TITLE: MAS 2rd ROUND



HIP OPERATIONAL SEQUENCE DIAGRAM

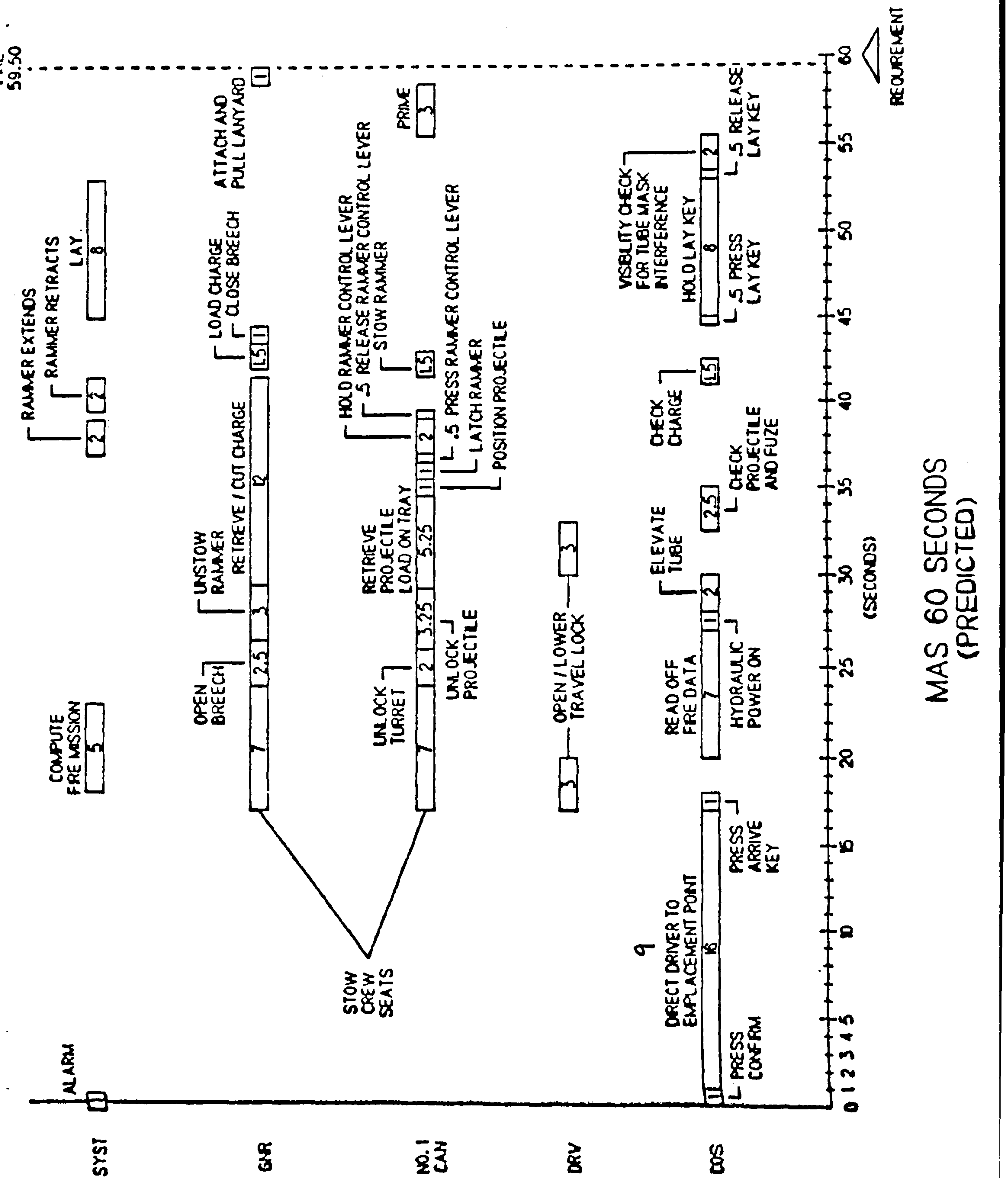
TITLE: MAS 2nd ROUND



Appendix B

Schematics, Timelines & Assumptions

Note: All of these materials are working documents provided by the HIP prime contractor MANPRINT team. They are not official or final estimates of crew or system performance.



MAS 60 SECONDS
(PREDICTED)
(SECONDS)
0 1 2 3 4 5 10 15 20 25 30 35 40 45 50 55 60
REQUIREMENT
FIRE
59.50
SYST
GNR
NO. 1 CAN
DRV
COS
ALARM
COMPUTE FIRE MISSION
5
RAMMER EXTENDS
RAMMER RETRACTS
LAY
8
2
2
STOW CREW SEATS
OPEN BREECH
UNSTOW RAMMER
RETREIVE / CUT CHARGE
7
2.5
3
12
LOAD CHARGE
CLOSE BREECH
1.5
1
ATTACH AND PULL LANYARD
UNLOCK TURRET
UNLOCK PROJECTILE
RETREIVE PROJECTILE LOAD ON TRAY
7
2
3.25
5.25
HOLD RAMMER CONTROL LEVER
.5 RELEASE RAMMER CONTROL LEVER
STOW RAMMER
.5 PRESS RAMMER CONTROL LEVER
LATCH RAMMER
POSITION PROJECTILE
PRIME
3
OPEN / LOWER TRAVEL LOCK
3
3
PRESS CONFIRM
DIRECT DRIVER TO EMPLACEMENT POINT
16
9
PRESS ARRIVE KEY
READ OFF FIRE DATA
7
HYDRAULIC POWER ON
ELEVATE TUBE
2
CHECK PROJECTILE AND FUZE
2.5
CHECK CHARGE
1.5
VISIBLITY CHECK FOR TUBE MASK INTERFERENCE
HOLD LAY KEY
8
.5 PRESS LAY KEY
.5 RELEASE LAY KEY
2

5/13/88

MAS 60 SECONDS TIMELINE DESCRIPTION
(Predicted)

	Crew Member	Event	Approx. Event Time	Approx. Accum. Time
1.	SYST	Fire Mission Alarm	0.00	0.00
2.	COS	Acknowledge Fire Mission	1.00	1.00
3.	COS	Direct driver to Emplace. Pnt.	16.00	17.00
4.	COS	Press Arrive Key	1.00	18.00
5.	DRV	Open Travel Lock	3.00	20.00
6.	GNR + No. 1	Stow Crew Seats	7.00	24.00
7.	GNR	Open Breech	2.50	26.50
8.	COS	Read Fire Data, Elevate Tube	10.00	30.00
9.	GNR	Prepare Rammer for Loading Project	3.00	29.50
10.	DRV	Lower Travel Lock	3.00	33.00
11.	No. 1	Unlock, Retrieve & Load Project	8.50	34.50
12.	COS	Check projectile and Fuze	3.00	35.00
13.	No. 1	Ram Projectile (Sequence)	7.00	41.50
14.	GNR	Retrieves and Cut Charge	12.00	41.50
15.	COS	Check Charge	1.50	42.50
16.	No. 1	Load Charge	1.50	43.50
17.	GNR	Close Breech	1.00	44.50
18.	COS	Lay Gun	9.00	53.50
19.	GNR	Vis. Check for Tube-Mask Interference	2.00	55.50
20.	GNR	Prime, Attach & Pull Lanyard	4.00	59.50

5/13/88

Assumptions for

MAS 1st Round Fired from Road March in 60 and 75 Seconds Requirement (Predicted)

ASSUMPTIONS:

1. All hatches are closed during road march and subsequent fire mission

2. Spades are not emplaced

3. Muzzle cover has been removed

4. Tangent / level terrain for emplacement

5. SPH stops from road march configuration after traveling 100 meters (upon confirming fire mission)

6. SPH is emplaced on general sector of fire (+/- 30 degrees azimuth)

7. ZUPT requirements are completed

8. Tube mask interference data is not collected or used

9. Mission will not require special clothing (i.e., Arctic or MOPP IV)

10. Personnel have opened propellant cannister, removed dunnage and closed cannisters during HIP uploading

11. Pre-fuzed rounds

12. Pre-set fuzes

13. Pre-fuzed projectile and propellant charge information available by pressing arrive and confirm button

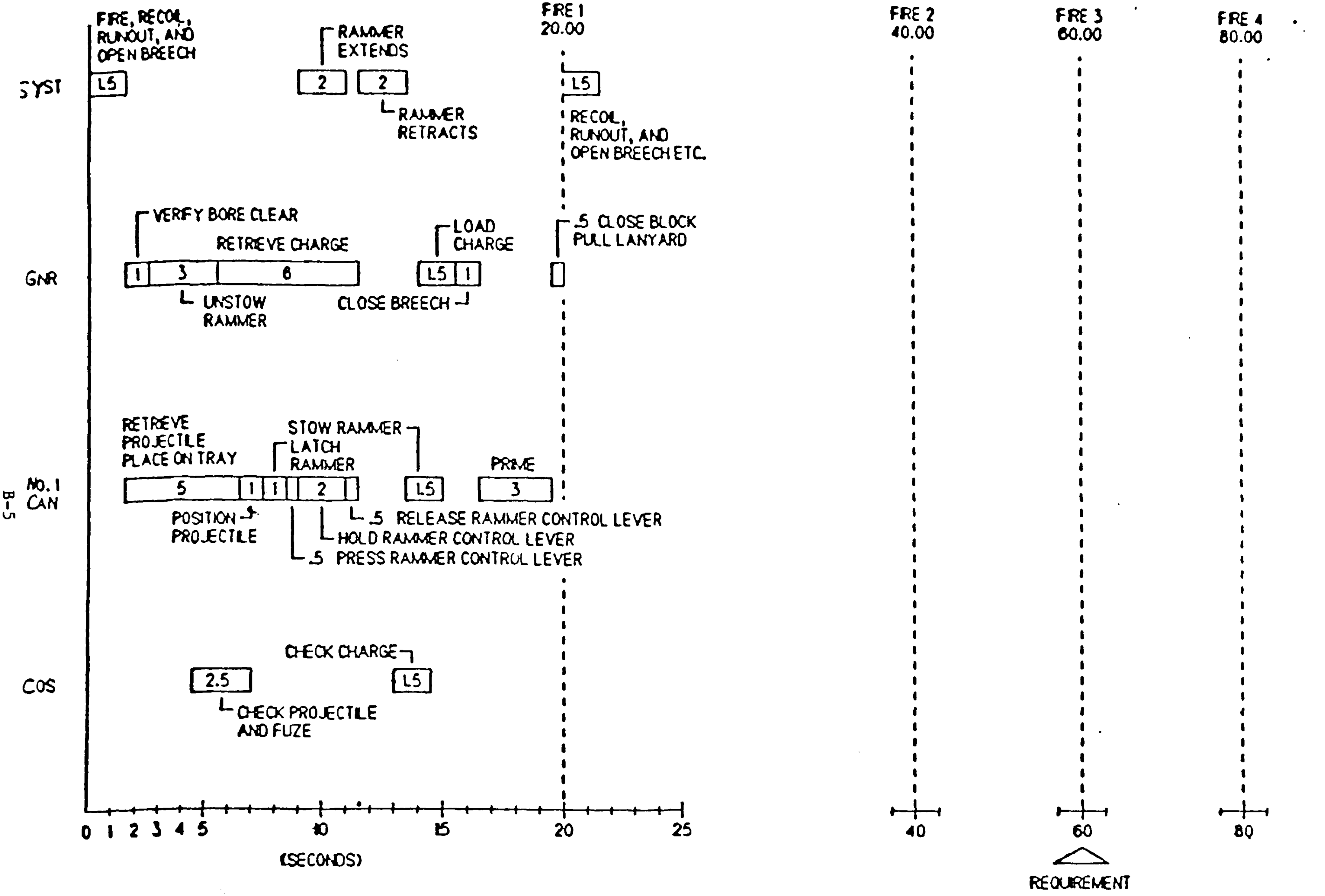
14. Projectiles are selected from ready-rack (bustle)

15. Human task times are based on a fully trained crew

16. Fresh, fully rested crew are utilized

17. Time starts when the fire mission is acknowledged and the time stops when the round is fired

18. Time-to-fire predictions are based on the depicted task times, crew member allocations, and sequence of task events



MAS 4 ROUND / MINUTE
(PREDICTED)

5/13/88

MAS 4 ROUND/MINUTE TIMELINE DESCRIPTION
(Predicted)

	Crew Member	Event	Approx. Event Time	Approx. Accum. Time
1.	SYST	Fire, Recoil, Runout & Open Breech	1.50	1.50
2.	GNR	Verify Bore Clear, Unstow Rammer	4.00	5.50
3.	No. 1	Retrieve and Load Projectiles	5.00	6.50
4.	COS	Check Projectile & Fuze	2.50	7.00
5.	GNR	Retrieve Charge	6.00	11.50
6.	No. 1	Position & Ram Proj., Stow Rammer	8.50	15.00
7.	COS	Check Charge	1.50	14.50
8.	No. 1	Load Charge	1.50	15.50
9.	GNR	Close Breech, Prime and Pull Lanyard	4.50	20.00

5/13/88

Assumptions for

MAS 4 Rounds/Minute Requirement
(Predicted)

ASSUMPTIONS:

1. All hatches are closed
2. SPH is emplaced
3. Spades are emplaced
4. Lanyard is pre-attached
5. Gun is on target
6. No azimuth or elevation changes during firing
7. Mission will not require special clothing (i.e., Arctic or MOPP IV)
8. Pre-cut charges
9. Pre-fuzed rounds
10. Projectile type is predesignated
11. Projectiles are unlocked
12. First six projectiles are selected from ready-rack (bustle), remaining projectiles are selected from rear left or right hull location
13. Pre-set fuzes
14. Loader rammer is in load (unlatched) position
15. No swabbing between rounds
16. Gun loading angle is same as firing angle
17. Turret electrical & hydraulic power is available
18. Personnel have opened propellant cannister, removed dunnage and closed cannisters during HIP uploading
19. Charge type is predesignated
20. Muzzle cover has been removed
21. Site data has been collected

(Continued)

5/13/88

Assumptions for

MAS 4 Rou..ds/Minute Requirement
(Predicted)

22. Seats are stowed

23. Human task times are based on a fully trained crew

24. Fresh, fully rested crew are utilized

25. Time starts when the first round is fired and time stops when the 13th round is fired

26. Time-to-fire predictions are based on the depicted task times, crew member allocations, and sequence of task events

Appendix C

Crew Drill Model Time Specifications

Note: Both of these displays are based on average times throughout a sequence running from row 1 to "Fire!" in row 38 or 20, respectively. Code numbers in parentheses were used to index the tasks in Micro SAINT model networks. Time is shown in seconds.

March Fire Time Specifications

Tasks	Start	Minimum	Average	Maximum
1 SYS Alarm!-------------(01)	0.00	0.00	0.00	0.00
2 COS Press confirm------(02)	0.00	1.00	1.00	1.00
3 COS Direct driver-------(03)	1.00	12.00	16.00	20.00
4 COS Press arrive key----(04)	17.00	1.00	1.00	1.00
5 DRV Open travel lock-----(05)	17.00	2.00	3.00	4.00
6 CAN Stow seats---------(06)	17.00	5.00	7.00	9.00
7 GNR Stow seats---------(07)	17.00	5.00	7.00	9.00
8 SYS Compute fire mission(08)	18.00	5.00	5.00	5.00
9 COS Pause for fire directions	18.00	2.00	2.00	2.00
10 COS Read off fire data---(41)	20.00	2.00	7.00	12.00
11 CAN Unlock turret-------(61)	24.00	1.00	2.00	3.00
12 GNR Open breech--------(71)	24.00	2.00	2.50	3.00
13 CAN Unlock projectile----(62)	26.00	1.75	2.50	3.25
14 GNR Unstow rammer-----(72)	26.50	2.50	3.00	3.50
15 COS Hydraulic on--------(42)	27.00	1.00	1.00	1.00
16 COS Elevate tube--------(43)	28.00	2.00	2.00	2.00
17 CAN Retrieve projectile--(63)	28.50	3.25	4.25	5.25
18 GNR Retrieve/cut charge-(73)	29.50	8.00	10.00	12.00
19 DRV Lower travel lock---(51)	30.00	2.00	3.00	4.00
20 COS Check projectile/fuze(44)	32.75	1.50	2.50	3.50
21 CAN Position projectile--(64)	35.25	1.00	1.00	1.00
22 CAN Latch rammer------(65)	36.25	1.00	1.00	1.00
23 CAN Press ram lever----(66)	37.25	0.50	0.50	0.50
24 CAN Hold ram lever-----(67)	37.75	2.00	2.00	2.00
25 SYS Extend Rammer-----(81)	37.75	2.00	2.00	2.00
26 COS Check Charge-------(45)	39.50	1.00	1.50	2.00
27 CAN Release ram lever--(68)	39.75	0.50	0.50	0.50
28 SYS Retract rammer-----(82)	40.25	2.00	2.00	2.00
29 GNR Load charge--------(74)	41.00	1.00	1.50	2.00
30 CAN Stow rammer-------(69)	42.25	1.50	1.50	1.50
31 GNR Close breech--------(75)	42.50	0.50	1.00	1.50
32 COS Press lay key-------(46)	43.50	0.50	0.50	0.50
33 COS Hold lay key--------(47)	44.00	4.00	6.00	8.00
34 COS Release lay key-----(48)	50.00	0.50	0.50	0.50
35 COS Check visibility-----(49)	50.50	1.50	2.00	2.50
36 CAN Prime charge------(601)	52.50	2.00	3.00	4.00
37 GNR Pull lanyard--------(76)	55.50	1.00	1.00	1.00
38 SYS ------FIRE!---------(77)	56.50	0.00	0.00	0.00

Volley Fire Time Specifications Fri, Nov 11, 1988 14:48

Tasks	Start	Minimum	Average	Maximum
1 SYS Fire & open breech ----(1)	0.00	1.50	1.50	1.50
2 GNR Verify bore clear -----(2)	1.50	0.75	1.00	1.25
3 CAN Retrieve projectile----(3)	1.50	3.00	4.00	5.00
4 GNR Unstow rammer------(21)	2.50	2.50	3.00	3.50
5 COS Check projectile-------(4)	5.50	0.00	0.00	0.00
6 GNR Retrieve charge -----(22)	5.50	4.00	5.00	6.00
7 CAN Position projectile ---(31)	5.50	0.75	1.00	1.25
8 CAN Latch rammer -------(32)	6.50	0.75	1.00	1.25
9 CAN Press ram lever-----(33)	7.50	0.50	0.50	0.50
10 CAN Hold ram lever ------(34)	8.00	1.50	2.00	2.50
11 CAN Release ram lever----(35)	10.00	0.50	0.50	0.50
12 SYS Rammer retracts ----(11)	10.50	1.00	1.00	1.00
13 COS Check charge---------(41)	10.50	1.00	1.50	2.00
14 SYS Rammer ret II -------(13)	11.50	0.60	0.60	0.60
15 GNR Load charge----------(23)	12.00	1.00	1.50	2.00
16 CAN Stow rammer -------(36)	12.10	1.00	1.50	2.00
17 GNR Close breech --------(24)	13.50	0.75	1.00	1.25
18 CAN Prime charge--------(37)	14.50	2.00	3.00	4.00
19 GNR Close block, pull lnyd (25)	17.50	0.50	0.50	0.50
20 SYS ------FIRE!----------(12)	18.00	0.00	0.00	0.00
21 Loop back to 1 for 12 rounds				
22 END of mission-----------(99)				

Appendix D

Cumulative Distributions by Error Rate

Note: The following information applies to each display.

The first column heading identifies time intervals of three seconds; the lower bound is shown until it is necessary to introduce breaks in the scale. Then both lower and upper bounds are shown.

The other column headings identify task error rates, 0% to 64%. These were the nominal rates set equal for two critical tasks. The crew error rate for either task or both is shown at the very bottom of each column. The sample size is 100 computer runs or simulated crew trials for each error rate.

The entries in each column down to 100.0 are exact cumulative frequencies or percentages. The decimal places are an artifact of our software necessary to include means, standard deviations and ratios in the stub.

	Time Interval	0%	1%	2%	4%	8%	16%	24%	32%	48%	64%
1	46	0.0	0.0	0.0	0.0	2.0	0.0	1.0	0.0	0.0	0.0
2	49	7.0	5.0	6.0	6.0	4.0	5.0	11.0	6.0	2.0	1.0
3	52	30.0	25.0	30.0	29.0	22.0	20.0	29.0	18.0	17.0	9.0
4	55	64.0	63.0	59.0	58.0	55.0	51.0	50.0	42.0	38.0	20.0
5	58	92.0	93.0	90.0	89.0	86.0	83.0	72.0	56.0	53.0	30.0
6	61	99.0	99.0	96.0	97.0	90.0	86.0	81.0	64.0	59.0	33.0
7	64	100.0	99.0	97.0	98.0	92.0	89.0	82.0	70.0	64.0	45.0
8	67		99.0	100.0	99.0	95.0	93.0	87.0	79.0	70.0	52.0
9	70		99.0		100.0	99.0	98.0	91.0	85.0	74.0	54.0
10	73		100.0			99.0	98.0	91.0	88.0	77.0	57.0
11	76					99.0	100.0	92.0	92.0	81.0	61.0
12	79					99.0		98.0	93.0	84.0	67.0
13	82					100.0		99.0	96.0	88.0	70.0
14	85							99.0	96.0	90.0	73.0
15	88							99.0	97.0	90.0	78.0
16	91							99.0	98.0	94.0	81.0
17	94							99.0	98.0	95.0	84.0
18	97							99.0	98.0	95.0	84.0
19	100							100.0	98.0	95.0	87.0
20	103								99.0	96.0	87.0
21	106								100.0	97.0	88.0
22	109									98.0	88.0
23	112									98.0	88.0
24	115									98.0	90.0
25	118									98.0	90.0
26	121									99.0	90.0
27	124									99.0	90.0
28	127									99.0	94.0
29	130									100.0	96.0
30	133										96.0
31	136										96.0
32	139										96.0
33	142										96.0
34	145										97.0
35	148										98.0
36	151										99.0
37	))) break (((										
38	250-252										100.0
39											
40	Average	56.7	57.2	57.1	57.0	58.3	58.9	60.1	63.3	67.1	79.6
41	Stand Dev	3.0	3.3	3.6	3.6	5.3	5.7	9.1	10.8	16.0	29.5
42											
43	Average/56.7	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.2	1.4
44	Stand Dev/3.0	1.0	1.1	1.2	1.2	1.8	1.9	3.0	3.6	5.3	9.8
45											
46	Crew Error %	0.0	1.2	4.0	7.8	15.4	29.4	42.2	53.8	73.0	87.0

	Time Interval	0%	1%	2%	4%	8%	16%	24%	32%	48%	64%
1	207	2.0	3.0	1.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0
2	210	14.0	12.0	16.0	9.0	3.0	0.0	0.0	0.0	0.0	0.0
3	213	54.0	43.0	39.0	31.0	13.0	1.0	2.0	1.0	0.0	0.0
4	216	84.0	80.0	59.0	54.0	37.0	7.0	4.0	2.0	0.0	0.0
5	219	99.0	95.0	83.0	73.0	60.0	22.0	8.0	3.0	1.0	0.0
6	222	100.0	98.0	91.0	83.0	74.0	31.0	17.0	5.0	1.0	0.0
7	225		99.0	98.0	95.0	84.0	42.0	19.0	6.0	2.0	0.0
8	228		99.0	99.0	97.0	89.0	51.0	30.0	13.0	3.0	0.0
9	231		99.0	100.0	99.0	96.0	63.0	37.0	20.0	3.0	0.0
10	234		99.0		99.0	98.0	72.0	46.0	23.0	3.0	0.0
11	237		100.0		100.0	98.0	82.0	55.0	30.0	5.0	0.0
12	240					99.0	85.0	62.0	35.0	5.0	0.0
13	243					99.0	91.0	67.0	41.0	7.0	0.0
14	246					100.0	94.0	71.0	50.0	10.0	1.0
15	249						96.0	74.0	57.0	12.0	1.0
16	252						96.0	78.0	64.0	13.0	1.0
17	255						96.0	79.0	69.0	15.0	1.0
18	258						98.0	81.0	75.0	17.0	1.0
19	261						100.0	86.0	78.0	22.0	1.0
20	264							90.0	84.0	25.0	1.0
21	267							92.0	85.0	27.0	1.0
22	270							94.0	89.0	31.0	2.0
23	273							94.0	89.0	33.0	2.0
24	276							94.0	91.0	34.0	2.0
25	279							96.0	94.0	37.0	3.0
26	282							99.0	95.0	41.0	3.0
27	285							100.0	95.0	48.0	4.0
28	288								96.0	51.0	5.0
29	291								98.0	56.0	6.0
30	294								98.0	65.0	8.0
31	297								99.0	68.0	9.0
32	300								99.0	70.0	11.0
33	303								99.0	70.0	13.0
34	306								99.0	72.0	14.0
35	309								99.0	74.0	17.0
36	312								99.0	76.0	22.0
37	315								99.0	77.0	23.0
38	318								99.0	80.0	26.0
39	321								99.0	83.0	27.0
40	324								99.0	84.0	29.0
41	327								99.0	89.0	34.0
42	330								100.0	89.0	36.0
43	333									91.0	39.0
44	336									92.0	43.0
45	339									93.0	48.0
46	342									93.0	48.0
47	345									95.0	49.0
48	348									95.0	52.0
49	351									96.0	52.0
50	354									96.0	53.0
51	357									98.0	57.0
52	360									98.0	58.0
53	363									99.0	62.0
54	366									99.0	67.0
55	369									99.0	68.0
56	372									99.0	71.0

	Time Interval	0%	1%	2%	4%	8%	16%	24%	32%	48%	64%
57	375									99.0	73.0
58	378									100.0	77.0
59	381										78.0
60	384										80.0
61	387										82.0
62	390										84.0
63	393										85.0
64	396										87.0
65	399										89.0
66	402										90.0
67	405										92.0
68	408										93.0
69	411										93.0
70	414										94.0
71	417-419										95.0
72	)Breaks Follow(										
73	429-431										97.0
74	444-446										98.0
75	468-470										99.0
76	477-479										100.0
77											
78	Average	216.1	216.4	217.2	218.9	223.1	230.8	243.4	256.1	287.4	368.5
79	Stand Dev	3.3	4.1	5.0	5.1	7.8	10.9	18.1	18.6	27.9	47.0
80											
81	Average/216.1	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.2	1.3	1.7
82	Stand Dev/3.3	1.0	1.2	1.5	1.5	2.4	3.3	5.5	5.6	8.4	14.2
83											
84	Crew Error Rate %	0.0	1.2	4.0	7.8	15.4	29.4	42.2	53.8	73.0	87.0

Appendix E

Acquiring and Using Micro SAINT Models

The Micro SAINT models can be requested from the second author. These models will be furnished on a Micro SAINT "Help/Networks/Results" diskette that will be compatible with version 2.1 and above of Micro SAINT. Please furnish a formatted diskette and a self-addressed, stamped return envelope with your request.

Send model requests to:

Chief
ARI Field Unit - Fort Hood
ATTN: SCOT Users Group (Dr. Nicholson)
HQ, TEXCOM (PERI-SHA)
Fort Hood, TX 76544-5065

Inquiries about Micro SAINT software and the Micro SAINT User's Guide should be directed to:

Micro Analysis & Design
3300 Mitchell Lane, Suite 175
Boulder, CO 80301